
2015 Dust Risk Standing Review Panel

Evidence Review for:

The Risk of Adverse Health and Performance Effects of Celestial Dust Exposure

Final Report

I. Executive Summary and Overall Evaluation

The 2015 Dust Risk Standing Review Panel (from here on referred to as the SRP) participated in a WebEx/teleconference with members of the Space Human Factors and Habitability (SHFH) Element, representatives from the Human Research Program (HRP), NASA Headquarters, and the NASA Research Education and Support Services on November 12, 2015 (list of participants is in Section IV of this report). The SRP reviewed the updated Evidence Report for The Risk of Adverse Health and Performance Effects of Celestial Dust Exposure (from here on referred to as the 2015 Dust Evidence Report), as well as the Research Plan for this Risk.

The SRP thinks the 2015 Dust Evidence Report is very well written, especially for a technical document and does an excellent job of integrating experimental summaries. The SRP was also impressed by the multiple experimental approaches used to document the dust permissible exposure limit (PEL).

II. Review of the Evidence for the Risk of Adverse Health and Performance Effects of Celestial Dust Exposure

1. Evaluate the 2015 Dust Evidence Report using the following criteria:

- A. *Does the 2015 Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?*

The 2015 Dust Evidence Report clearly points out that substantial empirical evidence supports an exposure-response relationship between crystalline silica and the risk of chronic inflammation, silicosis, fibrosis, and lung cancer, in a scenario in which exposures provoke inflammation, increased reactive oxygen and nitrogen species, pro-inflammatory mediators, and eventual damage to lung tissue, resulting in fibrosis and increased lung cancer risk. It relates this to celestial dusts indicating that they too may induce oxidative stress and inflammation, but how or why this may happen with celestial dusts is not clear.

- B. *Are the Risk Title and Statement properly stated in the current version of the HRP Integrated Research Plan (IRP)?**

Yes, the SRP thinks the Risk Title and Statement are properly stated in the current version of the IRP.

- C. *Is the text of the Risk Context provided in the HRP IRP clear?**

Yes, the SRP thinks the Risk Context provided in the IRP is clear.

D. Does the 2015 Evidence Report make the case for the research gaps presented?

In a review of ambient and environmental exposures to particles, the 2015 Dust Evidence Report notes that with occupationally relevant exposures to toxic silicates, processes other than inflammation likely contribute more substantially to the biologically significant endpoints. Further, such systemic oxidative stress is a mechanism by which inhaled toxic celestial dusts could affect the lung as well as other organs and may be relevant to the potential for chronic low level exposure to celestial dusts during prolonged periods of habitation on surfaces of celestial bodies. The connection between silica and celestial dust, however, is not explicitly made nor is there a specific gap in knowledge stated.

The review of the toxicity of similarly composed dusts, such as volcanic ash, is interesting but the Report does not make a compelling case for its relevance to the toxicological effects of celestial dusts. Presumably, the link is that lunar dust is similar in some aspects to volcanic ash (though not stated as such in the 2015 Dust Evidence Report) and there is a similar response in mice to the Martian dust simulant as there was for the lunar dust. The same is true for the comparison of Martian dust to the toxicity of desert sands which are noted as causing damage to the lung tissue through a direct physical effect, with cytokines and oxidative stress generated in the lesion contributing to acute toxicity. The underlying logic again appears to be to make a case for silica being the toxic component of celestial dust and the point of comparison to known terrestrial dust toxicity. However, none of that logic is made explicit and gaps are not clearly identified as such.

Although the 2015 Dust Evidence Report makes the case for the presented research gaps, one member of the SRP recommended a more explicit set of gaps be stated as:

1. Are celestial dusts similar to crystalline silica in their toxicological effects on humans?
2. Does celestial dust provoke inflammation, which produces increased oxygen and nitrogen species, pro-inflammatory mediators, and eventual damage to lung tissue and epithelial hyperplasia, resulting in fibrosis and increased lung cancer risk?
3. Is systemic oxidative stress a mechanism by which inhaled toxic celestial dusts could affect other organs and would this be relevant to chronic low levels of exposures for celestial dusts during prolonged periods of habitation on surfaces of celestial bodies?
4. Are the effects of exposure to different celestial dusts (e.g., Martian dust or Lunar Dust from sites not yet sampled or tested) similar to the currently tested Lunar Dust and can the same exposure limit be applied?

Finally, the 2015 Dust Evidence Report clearly delineates the lack of relevant evidence, thus the SRP agrees with the deletion of the “Extraterrestrial Dust – Carbonaceous Asteroid risk.

E. Are there any additional knowledge-type gaps or areas of fundamental research that should be considered to enhance the basic understanding of this specific Risk?

As presented in the 2015 Dust Evidence Report, the need to evaluate the cardiovascular risk is important although the population of astronauts is very healthy by design so there is a lower risk or concern. Despite this lower risk for healthy astronauts, the SRP thinks, given the acute effects of short-term exposure to airborne particles, the Evidence Report would benefit by a more complete discussion on the acute (short term) cardiovascular risk of inhaled particles. Specifically, the epidemiological literature discussion could be expanded to note that myocardial infarction (MI) rates increase within one to two hours of self-reported being in traffic (Peters et al., 2013) and that there are various reports of MI rates increasing within 24 hours of an increase in ambient particulate matter (PM_{2.5}) (e.g., Rich et al., 2010). Both of these papers, among others highlight that the risk of triggering an acute MI (presumably in individuals who already have atherosclerosis) may occur over extremely short time spans of exposure to air pollution.

Peters AI, von Klot S, Mittleman MA, Meisinger C, Hörmann A, Kuch B, Wichmann HE. Triggering of acute myocardial infarction by different means of transportation. Eur J Prev Cardiol. 2013 Oct;20(5):750-8. doi: 10.1177/2047487312446672.

Rich DQ, Kipen HM, Zhang J, Kamat L, Wilson AC, Kostis JB. Triggering of transmural infarctions, but not nontransmural infarctions, by ambient fine particles. Environ Health Perspect. 2010 Sep;118(9):1229-34. doi: 10.1289/ehp.0901624.

The evaluation of immune changes and interactions between microgravity and dust effects is important as outlined. The similarity of some extraterrestrial dusts to silica (crystalline) is of concern and, as already mentioned, the SRP believes the potential for lung fibrosis is a gap that needs additional attention despite the completion of the Study of Lunar Dust and Lunar Simulant Activation, Monitoring, Solution, and Cellular Toxicity Properties. This is particularly true if the ground lunar dust can produce an order of magnitude more hydroxyl radicals than can ground quartz (as stated in the abstract and aims section of the Task). In fact, this startling account seemed a bit incredulous given the ability of pure alpha-quartz to function in oxidant production and needs confirmation. Nevertheless, this evidence suggests additional research on the long-term effects of extraterrestrial dust may be necessary (likely, in vivo studies), but some confirmatory chemical tests may be warranted for expediency.

Additionally, as stated in the 2015 Dust Evidence Report, dust on an extraterrestrial body can and will be different based upon the region and source of the collected dust sample. It would seem reasonable to start building an inventory of dusts with a variety of compositional and physical structure so that differences in the source of celestial dusts can be related and, with time, some informative inferential indices for less well-understood potential exposures can be developed. As more samples become available, ongoing toxicity evaluations should be done, as outlined in Dust 14.

F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP IRP?

The SRP is pleased with the interactions between the Dust discipline and other HRP disciplines.

G. Is input from additional disciplines needed?

The 2015 Dust Evidence Report should include a discussion on the potential for acute MI effects after particle exposure, as noted above.

H. Is the expertise of the authors sufficient to fully cover the scope of the given risk?

Yes, the SRP strongly believes that the team of authors is very knowledgeable and sufficient to cover the scope of the risk.

I. Is there information from other HRP disciplines that need to be included in the 2015 Evidence Report?

The SRP thinks information from other groups in the Space Human Factors and Habitability Element should be included in the 2015 Dust Evidence Report. Specifically, the Space Human Factors Engineering Project can address measures to reduce dust intrusion into living areas through design of the living area and the design of entry and exit procedures.

J. Is the breadth of the cited literature sufficient?

Yes, the breadth is adequate but one SRP member suggested that it was possibly a little long in some aspects regarding the adverse effects of ambient particulate matter (PM) (i.e., more concise references to the literature rather than the longish review would be sufficient). In many areas of the 2015 Dust Evidence Report, one SRP member suggested referencing the Integrated Science Assessment for PM prepared by the US Environmental Protection Agency to find answers and relevant citations that can save a lot of work and have less reliance on reports and publications that are follow-up rather than primary sources.

K. What is the overall quality and readability of the 2015 Evidence Report?

Overall, the SRP thinks the quality of the 2015 Dust Evidence Report is outstanding and the inclusion of the anecdotal evidence of lunar dust effects on Apollo astronauts is critically important to the risk identification.

The writing is generally clear and very thorough and presents sufficient evidence that the risk of exposure to lunar or Martian dust is significant and relevant to long-term missions in space. There are a few places where there are typographical or spelling errors. Also, there are some text references that do not have a corresponding bibliographic link (e.g.,

on page 9, the Rowe 2000 and on page 23 Bai et al., 2007 references are not in the bibliography). One point of error appears on page 9 where it is stated that ultrafine PM ($<0.1 \mu\text{m}$) is derived from abrasive wear from tires and brakes. Rather, this type of particle generation leads to coarse particles ($>2.5 \mu\text{m}$). Ultrafine particles generally appear in the environment as a result of combustion or condensation from hot gases.

III. 2015 Dust Risk SRP Evidence Review: Statement of Task for the Risk of Adverse Health and Performance Effects of Celestial Dust Exposure

In 2008, the Institute of Medicine (IOM) reviewed NASA's Human Research Program (HRP) Evidence Books that describe the Risks that were identified in NASA's Human Research Program Requirements Document (PRD). The 2015 Evidence Report for the Risk of Adverse Health & Performance Effects of Celestial Dust Exposure (Dust Risk) has not been reviewed since the last IOM review and there have been significant changes to the evidence base for the Risk.

The 2015 Dust Risk Standing Review Panel (SRP) is chartered by the Human Research Program (HRP) Chief Scientist to review the updated Evidence Report for the Dust Risk. The 2015 Dust Risk SRP will evaluate the Evidence Report and generate a final report of your analyses of the evidence base, including any recommendations on how to improve the current Evidence Report, and submit it to the HRP Chief Scientist. Your report will also be made available on the Human Research Roadmap (HRR) website.

The 2015 Dust Risk SRP is charged to:

1. Evaluate the 2015 Dust Risk Evidence Report based on each of the following criteria:
 - A. Does the 2015 Evidence Report provide sufficient evidence that the Risk is relevant to long-term space missions?
 - B. Are the Risk Title and Statement properly stated in the current version of the HRP Integrated Research Plan (IRP)?*
 - C. Is the text of the Risk Context provided in the HRP IRP clear?*
 - D. Does the 2015 Evidence Report make the case for the research gaps presented?
 - E. Are there any additional knowledge-type gaps or areas of fundamental research that should be considered to enhance the basic understanding of this specific Risk?
 - F. Does the Evidence Report address relevant interactions between this Risk and others in the HRP IRP?
 - G. Is input from additional disciplines needed?
 - H. Is the expertise of the authors sufficient to fully cover the scope of the given risk?
 - I. Is there information from other HRP disciplines that need to be included in the 2015 Evidence Report?
 - J. Is the breadth of the cited literature sufficient?
 - K. What is the overall quality and readability of the 2015 Evidence Report?
2. Provide comments on any important issues that are not covered by the criteria in #1 above.

** Please be aware that any suggested changes to the Risk Title, Statement, and Risk Context by the SRP may need to be approved by the Human Systems Risk Board (HSRB). The HSRB has the overall responsibility to implement and maintain a consistent, integrated process for assessing, documenting, and tracking all risks to the human system associated with spaceflight activities (both in flight and post flight).*

Additional information regarding this review:

1. Participate in a WebEx conference call on November 12, 2015 at 11:30 am ET to discuss the Evidence Report with the Space Human Factors and Habitability (SHFH) Element.
2. Prepare a draft final report within one month of the WebEx conference call that contains a detailed evaluation of the Evidence Report specifically addressing items #1 and #2 of the SRP charge. The draft final report will be sent to the HRP Chief Scientist and he will forward it to the appropriate Element for their review. The SHFH Element and the HRP Chief Scientist will review the draft final report and identify any misunderstandings or errors of fact and then provide official feedback to the SRP within two weeks of receipt of the draft report. If any misunderstandings or errors of fact are identified, the SRP will be requested to address them and finalize the 2015 SRP Final Report as quickly as possible. The 2015 SRP Final Report will be submitted to the HRP Chief Scientist and copies will be provided to the SHFH Element that sponsors the dust discipline and also made available to the other HRP Elements. The 2015 SRP Final Report will be made available on the HRR website (<http://humanresearchroadmap.nasa.gov/>).

To clarify, the Risk Statement and Risk Context are defined as follows:

Risk Statement:

“Given the CONDITION, there is a possibility that a CONSEQUENCE will occur”.

Condition: a single phrase briefly describing current key circumstances, situations, etc. that are causing concern, doubt, anxiety, or uncertainty – something that keeps you up at night.

Consequence: a single phrase or sentence that describes the key, negative outcome(s) of the current conditions.

Notes:

The condition-consequence format provides a more complete picture of the Risk, which is critical during mitigation planning. The condition component focuses on what is currently causing concern. This is something that is true or widely perceived to be true. This component provides information that is useful when determining how to mitigate a Risk.

The consequence component focuses on the intermediate and long-term impact of the risk. Understanding the depth and breadth of the impact is useful in determining how much time, resources, and effort should be allocated to the mitigation effort.

A well-formed Risk Statement usually has only one condition, and has one or more consequences.

Risk Context:

Purpose: provide enough additional information about the Risk to ensure that the original intent of the Risk can be understood by other personnel, particularly after time has passed.

Description: capture additional information regarding the circumstances, events, and interrelationships not described in the Risk Statement.

An effective context captures the what, when, where, how, and why of the Risk by describing the circumstances, contributing factors, and related issues (background and additional information that are NOT in the Risk Statement).

IV. Dust Risk SRP Research Plan Review WebEx/Teleconference Participants

SRP Members:

Terry Gordon, Ph.D. (Chair) – New York University School of Medicine
Dan Costa, Sc.D., DABT – EPA/ORD
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V. 2015 Dust Risk SRP Roster

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